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DEMONSTRATION AND PERFORMANCE EVALUATION OF A SOLAR LUMBER DRY KILN IN WESTERN MONTANA

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DEMONSTRATION AND PERFORMANCE EVALUATION OF A SOLAR LUMBER DRY KILN IN WESTERN MONTANA

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INTRODUCTION

Construction on a 6500 bd. ft. capacity (1 inch basis) solar dry kiln was begun in July, 1981. The passive-gain wood-frame structure incorporates features previous solar kilns such as an insulated wood floor, double-skinned glazing, R-19 insulated North, East and West walls and cart-trak lumber trolley system for ease of loading and unloading. Extensive monitoring of the kiln's performance is accomplished through a data logging system attached to pyranometers, humidity sensors and thermisters to measure both inside and outside solar radiation humidity and temperature. The interior air circulation system and the moist-air ventilation system is also controlled by the data logger. Moisture content of boards in 12 locations throughout the stack are measured and recorded automatically by an electronic moisture detection system. A more detailed description of the construction of the dry kiln follows and is supplemented with illustrations of the completed structure.

I. Project Progress June 23, 1981 - August 25, 1982

Site Locations

The three-acre site of the solar dry kiln is located within the confines of the University of Montana School of Forestry's Lubrecht Experimental Forest, 30 miles east of Missoula on State Highway 200. The kiln is located near the school's sawmill, and integrated with that facility in terms of project scope and sizing. (Figures 1, 2). The kiln faces south-10 degrees west to take advantage of a natural opening in the surrounding forest. In addition to the natural opening, trees have been cleared to a radius sufficient to minimize shading in the winter.

Weather data for 20 years were used to determine design parameters and estimate kiln efficiency. (see Tables 1 and 2). Since this kiln is using design features, construction techniques and materials never integrated in a single lumber dry kiln before, these data are conservative estimates of performance.

Foundation

The dry kiln foundation is a perimeter footing-wall, 36 inches deep by 12 inches wide. The same design is used for supporting the cart tracks. The whole perimeter-track foundation is reinforced with 5/8 inch diameter steel reinforcing rod ("rebar"). Six inch wide steel channel serves as a bearing plate for the track foundation to which is attached the 4 inch thick wooden floor. Steel channel and "I" sections are also used in other areas of critical stress and impact loading - such as the track foundation-perimeter intersections and perimeter corners.

Framing

The kiln utilizes conventional balloon construction with 2 x 6 wall studs set on 24 inch centers. The roof is supported at its 45° angle by a combination 2 x 8 and 2 x 6 manufactured arch, with the 2 x 6 portion supporting the front wall at a 70 degree (from horizontal) angle. The arch members, 2 x 8 and 2 x 6, are joined by means of a bolted joint and 3/4 inch A-C-X plywood gussetts on either side of the joint. The floor is joined to the perimeter and track support foundation with bolts embedded in the concrete or welded to the track bearing plates. The loading area directly west of the door is also connected to the track foundation with bolts. This loading area also has track mounted to it and allows easy loading of the charge onto carts, which can then be rolled into the kiln.

Insulation

Six-inch fiberglass batts were used as insulation due to its fire-proof nature when exposed during construction. Poly urethane foam was also considered, but since there was a high likelihood that the interior sheathing would take several months to complete after insulating, the risk of serious fire and toxic fumes, during welding operations precluded its use. A six mil polyethylene vapor parrier was installed under the interior sheathing to prevent moisture migration into the insulation, lessening its effectiveness.

Sheathing

The outside of the building was sheathed with 5/8 inch C-D-X Fir-Larch plywood. The inside sheathing, which serves as the interior finished walls is 3/4 inch CDX plywood. The greater thickness was chosen for use in the inside because electrical conduit and fixtures were to be fastened to it, and it would also have greater resistance to mechanical damage. The inside sheathing was completely caulked and sealed to reduce moisture and heat flow through the walls.

Exterior Siding

The exterior of the dry kiln was sided with T1-11 exterior plywood siding and the finish trim of 1 inch by 4 inch lodgepole pine applied. The exterior siding was immediately stained with a special decay and weather resistant stain formulated and mixed in the School of Forestry, Wood Science Laboratory. The trim was primed and painted in a complimentary ultraviolet screening brown exterior enamel.

Glazing

The kiln glazing chosen for this project had to possess certain properties in order to be commercially feasable. First of all the light transmissiveness had to be high, while the heat transfer coefficient, U, had to be low. The material had to be strong enough to support heavy snow loads, light weight for ease of application and repair, and the ability to withstand ultraviolet radiation without buttle-oxidation or yellowing. The material chosen must also have good impact strength in addition to its flexural strength, in order to survive the abuse it will undergo in a commercial sawmill environment.

Tuffak-Twinwal, a Rhom and Haas extruded, double wall polycarbonate sheet exhibits these qualities of thermal insulation, light transmission, strength durability and light weight. Table 3 presents the technical data of this product.

Table 3. Tuffak-Twinwal design data used in evaluation.

PROPERTY	REPRESENTATIVE VALUE
U-factor	0.62 BTU/hr/sq.ft/^{o}F
R value	0.76 BTU/hr/sq.ft/^{o}F
White Light Transmission	80%
Solar Transmission	77%
Air Cannon Impact Strength (0.62 lb dart at 75 mph)	100 ft-lb no break
UL-972 Impact Strength (5 lb steel ball from 40 ft)	200 ft-lb no break
Coefficient of Expansion (Averaged over -30^{o}C to +30^{o}C)	3.3 x 10-^{5} in/in/^{o}F
ASTM E.84 Tunnel Test*	Flame Spread = 0* Fuel Contribution = 0 Smoke Density =185
NBS Smoke Chamber	24% minimum transmission after 7 minutes.
Flexural Moment of Inertia	Parallel = .00034 in^{4}/in width Perpendicular = .00021 in^{4}/in width
Compressive Strength	137 lbs/sq.in
Weight	0.25 lb/sq.ft

Table 3 cont.

*Although TUFFAK-TWINWAL received a flame spread reading of zero, it was noted that the TUFFAK-TWINWAL ignited 30 seconds after the start of the test and there was melting, sagging, warping, dripping and flaming dripping of the sample for the first 12 feet of the tunnel. However, there was no flame front advancement and therefore, a rating of zero was obtained. This rating does not provide a basis for predicting how the material will behave under actual fire conditions.

The glazing was fastened, as per manufacturer's instructions, using Tru-Grip fasteners with rubber washers, etc. (see Figure #3). Joint gaps were filled with silicone caulking and covered with either stained 1 inch by 4 inch wood trim strips or specially formed "Z"-shaped sheet metal on the laterally oriented joints and sealed with roofing asphalt.

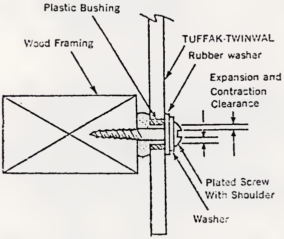
Plastic Bushing
Wood Framing
TUFFAK-TWINWAL
Rubber washer
Expansion and Contraction Clearance
Plated Screw With Shoulder
Washer

Figure 3. Sectional view of glazing mounting design.

After the roof and front wall arches and bracing were painted flat black, and the glazing was applied, an internal black collector plate was installed on the lower side of the arches. The plate was made up of 4 foot by 10 foot long panels of texturized, ribbed aluminum, specially made by the Reynolds Aluminum Corporation for solar collectors. The plate is supplied primed and painted black on one side, white-primed on the reverse. Before installation, the primed side was painted with two coats of flat Black polyurethane enamel. The panels were also installed with Tru-Grip fasteners.

The black collector plate was included in the design of the kiln to increase collection and transmission of heat. It also affords protection for the lumber stack from direct solar radiation which overdries and degrades lumber on the south and top side of the charge. The collectors work in conjunction with the glazing to transform the air space between the arches into a heat exchanger-plenum, quite similar to a direct-gain, solar hot air collector. Intake and exhaust slots are located in the lower front wall, near the circulating fans and at the junction of the roof and back wall. The aluminum plate also serves as an internal roof to help protect the lumber from water leaks or condensation forming on the interior glazing surface.

Door

The 9 and ½ foot square door to the kiln is a sliding track door, moving to the north, located in the west wall of the kiln (Figure 4). It exhibits the same construction materials and methods of the kiln and includes a 24 inch by 40 inch high access door which eliminates the need to open the large door to gain entry to the kiln during operation (Figure 5). This allows for less escape of heat from the kiln upon entry and exit.

Track and Carts

Moore-Oregon dry kiln carts were donated to the project by Champion International Corporation. The carts ride on 55 lb/yard rail donated by the Burlington Northern Railroad and Pyramid Mountain Lumber Corporation. The rail was bolted to the 4 inch thick floor and outside loading ramp. Since the track was used and well worn, extensive grinding was necessary to remove to rolled lip on the bearing surface of the rail. The track extends through the doorway, thus necessitating a small removable section in each rail to allow passage of the sliding door. After the rail was laid and ground, the floor of the kiln was covered with 4 inches of washed pea gravel to serve as moisture absorbent and heat sink.

Circulating Fans

The 3 - 30 inch diameter circulating fans are mounted directly above and slightly north of the east-west centerline of the lumber charge, (Figure 6). The drive shaft is connected to the fan hub and passes through the north wall where it is connected, by means of a belt-pulley system to an exterior-housed 0.33 horsepower, open frame, reversible, capacitor start motor, (Figure 7). Changing pulley diameters allows for changing the rotation speed, and hence the volume displacement, of the fans. Baffling and proper stickering the lumber charge insures that the air will pass directly through the courses of lumber, rather than over under or around the charge. The circlating fans and collector system was designed to draw air across the collector plates, through the lumber stack and back over the collector plates for reheating. The fans should be periodically reversed to assure uniform drying on both sides of the charge.

Ventilation System

As the warm, dry air passes over the layers of lumber held apart by rows of 0.75 inch thick stickers, it evaporates and absorbs water from the lumber. As this process continues, the relative humidity inside the kiln will increase while the temperature will drop. Since the drying rate is inversly related to relative humidity, it is of major importance to maintain as low a relative humidity as possible in the kiln to maximize the drying rate. A humidity controlled powered ventilating system was designed and installed in the dry kiln to help control humidity in the dry kiln.

The system consists of two 0.10 horsepower 10 inch diameter exhaust fans mounted 30 inches above the floor in the north wall. Automatic opening and closing louvered vent covers were included with the fans, to restrict air flow and heat loss. (Figure 8) The intakes for the exhaust fans are located on the front edges of the east and west walls, approximately 48" above ground level, (Figure 9). These intake vents are electrically operated and cannot be blown open or closed by wind gusts. They are wired parallel with the exhaust fans to open when they are activated by a humidity sensor.

Electrical Wiring

The primary electric service was brought to the kiln site by the School of Forestry in July. The 200 ampere-240 volt secondary service was extended to the dry kiln underground and powers the 3 - 0.33 horsepower circulating fans, the two 0.10 horsepower exhaust fans, the two powered intake vents, data logging and moisture detection equipment and lights and service outlets inside the kiln. The reversing, circulating fans are interfaced and operated by the data logging system through time adjustable relays. Delay timer relays are also used inconjunction with a reversing magnetic contactor to allow the fans to stop rotating before reversal. The duration of fan run in either direction is independently adjustable from 0.5 to 10 hours. For example, it is therefore possible to run the fans one direction for 4 hours, reverse and run for 8 hours; reverse and run for 4 hours, etc.

Instrumentation

Lii-Cor Inc. silicone pyranometers were purchased and installed for measuring interior (net) and external (gross) solar radiation in order to determine efficiency of the glazing-collector system. Data front thermistors for measuring inside and outside temperature will be used to determine the kiln's net heat gain and loss and control the circulating fans which are activated only above a prespecified temperature (set point). Humidity sensors are also linked to a data logging system and activate the ventilation system when a predetermined humidity level inside the kiln is met or exceeded.

A Campbell Scientific data logging system with the ability to monitor and record input data from 9 separate sources and store it for playback to a computer was chosen to fulfill the need of data collection equipment, (Figure 10). This equipment can be left for long periods of time (up to 3 weeks) and still assemble numerous readings from several sensors. The data logger periodically empties its memory onto a cassette tape which can then be fed into a computer, by means of an interface, and a complete statistical analysis of the data performed. This same data logger can also control up to 4 separate functions in the kiln based on up to four different input sources. In this application, the data logger automatically controls the air circulation and ventilation system. Capability of controlling 2 other pieces of equipment or systems, such as insulated shades or movable hot air collectors exists.

Lumber moisture content is measured by means of a Delmhorst resistance-type moisture meter (Figure 11). This device can electronically measure the moisture content of both the outside and center of 12 different specimen boards and graphically store these data on a strip-chart recorder. With these extensive data, conclusions can be drawn concerning the efficiency and feasibility of this design for commercial application.

Summary

Current Status

The solar lumber dry kiln has been completed and is now ready to undergo the first test run of lumber before actual measurements begin. This text run is necessary to insure that all design, operating and data collection systems are functioning properly. Champion International Corporation along with other firms in the Inland Empire, Rocky Mountain region have willingly donated the use of over 100,000 bd. ft. of lumber for testing. The principal investigator has made arrangements with these firms to specially handle the lumber in regards to grading and packaging before drying, as well as surfacing regrading and end trimming in order to compare a solar kiln charge with a matched air-dried charge dried adjacent the dry kiln. These comparisons of drying time, quality and volume recovery are basic to the economic analysis of the kiln's commercial feasibility.

In conclusion, the energy of over 3100 man hours has been directed to constructing the first commercially sized solar powered lumber dry kiln in this hemisphere. Design features aimed at increasing efficiency and lowering drying costs have been incorporated with innovative technology to produce a prototype kiln for cold, northern climates. Operational readiness tests are now in progress, and the first test charge will soon be loaded and monitored. The test runs will be conducted under the conditions set forth in the project scope of the second year's contract.

II. Involvement with Department

We have been fortunate to be able to use the Department personnel whenever necessary. The necessity has been infrequent but the times we have needed to clear up a problem or question (concerning billing procedures and format for reports), Department personnel have answered the questions immediately.

A Department employee stopped by the site in August 1981 and partially filled out a questionnaire concerning our progress. At that time, we were in the beginning stages of construction and had very little to show him.

A 2 month extension was suggested by the DNRC to offset the delay in construction caused by abnormally inclement construction weather during November 1981 through April, 1982. A delay was also caused by the DNRC review and subsequent rejection of a proposal for additional funding for bringing adequate electrical service to the kiln area. All things considered, contact and interaction with the department have been constructive. Program administrators and engineers have been invited to see the project but have not yet visited the site due to other commitments.

III. Publicity

The Solar Kiln Project has received local, regional and national publicity through various tours, presentation of papers, announcements and Forest Marketing Bulletins. Specifically:

1. 40 Montana Division of Forestry personnel toured the sawmill-kiln complex in early October, 1981.
2. 56 School of Forestry Alumni toured the same facilities on October 23, 1981.
3. Foresters from Champion International Corporation in Bonner, MT toured the facility in late October, 1981.

Specific inquiries as to technical data, costs, design, etc. have been received from the following:

1. Champion International Corporation -- Bonner, MT
2. Plum Creek Lumber Co. -- Columbia Falls, MT
3. Castle Mountain Lumber Co. -- White Sulphur Springs, MT

4. Real Log Homes, Inc. -- Missoula, MT
5. Bob Cook and Howard Fly, manufacturers of wooden arrow shafts -- Ovando, MT
6. W. H. Erskine Co., manufacturer of oak staircases -- Minong, WI
7. Dept. of Forest and Wood Sciences, Colorado State University -- Fort Collins, CO
8. Dept. of Forest Products, University of Idaho -- Moscow, ID
9. Barrie McDonald -- Sawmill owner and operator -- Grasmere, B.C.
10. Glacier Log Homes, Inc. -- Whitefish, MT
11. Gary Mallums, Powder River Timber Co. -- Osage, WY

Papers and presentation of the research were given at:

1. Western Wood Products Clinic Annual Meeting, Coeur d'Alene, ID, May 4, 1981.
2. Annual Meeting of the Forest Products Research Society -- Minneapolis, MN, June 1981.

The Solar Kiln Project was presented to the members of the Montana Woodland Council at the annual R. A. D. meeting in Bozeman, Montana, December 15, 16, 1981.

A paper discussing the kiln was presented to the Rocky Mountain Forest Industries Conference in Kalispell, MT in April of 1982. This meeting was well attended by numerous State, Federal, Corporate and individual forest managers and wood products specialists from the 8 state Rocky Mountain Region.

This Project saw numerous inquiries from individuals and companies interested in solar lumber driers. Of particular interest is the visit in July by officials of the Powder River Timber Co. of Osage, Wyoming. Mr. Mallums, mill manager, has decided to begin construction of a 36,000 bd. ft. capacity kiln in mid-September. This building will be designed after our project with design alterations and additional features suggested by the P. I..

IV. PROJECT EXPENDITURES

	DNRC	U of M	Other	Total
LABOR (Salaries and Fringe Benefits)				
Project Director	$5177.90	$7366.		$12543.90
Hourly technicians	6621.76			6621.76
Total Benefits	1303.16	1136.		2439.16
	$13102.82	8502.		$21604.82
Building Supplies				
Lumber, plywood, insulation	2645.87	1075.		3720.87
Glazing	1004.80			1004.80
Collector plate	372.80			372.80
Steel	947.60	235.	190.	1372.60
Concrete	1032.80			1032.80
Electrical Supplies	708.31	3400.		4108.31
Fans, motors, etc.	1538.83			1538.83
Tool Rental	30.00			30.00
Paint	596.62			596.62
Hardware	636.89			636.89
Tools	752.26			752.26
Miscellaneous Materials	373.39			373.39
Kiln carts			1800.	1800.00
Rail			1650.	1650.00
	$10640.17	$4710.	$3640.	$18990.17
Equipment				
Moisture Detection Equipment	1147.50	875.		2022.50
Data logger and probes	2996.80			2996.80
Computer interface and cassette recorders	1529.19			1529.19
Repairs	100.00			100.00
	$5773.49	$ 875.		$6648.49
Communications				
Xerox	$ 108.60			$ 108.60
Travel	$1761.92			$1761.92
Indirect Costs	$4117.00	$1700.		$5817.00

Budget Summary	DNRC	U of M	Other	Total
Total Salaries, Wages, Fringe Benefits	$13102.82	$8502.		$21604.82
Total Building Supplies	10640.17	4710.	$3640.	18990.17
Total Equipment	5773.49	875.		6648.49
Total Communications	108.60			108.60
Total Travel	1761.92			1761.92
Total Indirect Costs	4117.00	1700.		5817.00
PROJECT TOTAL	$35504.00	$15787.	$3640.	$54931.00

V. LABOR

Over 3100 man-hours were expended during the 14 month course of the project. Of these, approximately 1600 were funded by the School of Forestry and 1500 were funded by the Department of Natural Resources.

VI. Recommendations

The solar dry kiln appears to be a feasible means of drying lumber and anyone interested in this technology should contact the project director. Hopefully, someone from the Department of Natural Resources will visit the project to attain a good understanding of the kiln and solar lumber drying.

Construction and preliminary drying activity makes it evident that improvements in drying time, compared with air drying, are likely. It is also evident that an insulating device for the front wall and roof would help speed up the drying schedule even more.

Another area of improvement would be the use of active hot air collectors for preheating the make-up air.

In conclusion, the solar dry kiln is a straight-forward, easy-to-build structure that has the potential for decreasing drying costs for small sawmills, and enabling them to enter new markets with a higher quality product.

TABLE 1

Daily Maximums and Minimums of Solar Radiation
(langlies per day)

Month	1966		1967		1968		1969		4 Year Average	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Jan.	---	---	229	24	212	48	222	17	221	30
Feb.	---	---	317	68	362	63	390	75	357	69
Mar.	---	---	459	95	462	19	503	156	475	90
Apr.	628	125	614	116	657	19	604	112	626	93
May	708	380	742	199	736	202	690	175	719	239
June	749	120	729	217	725	158	749	156	738	163
July	703	349	745	449	866	299	891	337	801	358
Aug.	678	255	640	504	667	61	740	195	681	254
Sep.	564	162	466	140	488	138	561	99	520	135
Oct.	386	75	392	44	382	66	396	121	389	77
Nov.	200	35	287	39	239	33	224	50	233	39
Dec.	176	44	202	35	166	13	188	33	183	31

Data obtained from an
eppley pyrheliometer applied
to a chart recorder.

TABLE 2

Solar Radiation By Years and Months
(Average Langlies Per Day)

	YEAR				
	1966	1967	1968	1969	Four Year Average
January	--	100	133	104	111
February	--	189	196	228	202
March	--	285	232	385	298
April	434	405	325	412	394
May	574	489	500	559	530
June	497	478	467	516	490
July	622	630	588	640	620
August	508	589	445	558	525
September	390	384	309	358	360
October	231	208	220	241	225
November	103	137	127	142	127
December	108	107	84	90	97

Data obtained from an
eppley pyrheliometer applied
to chart recorder.

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